# Laboratory Demonstration of Low Earth Orbit Inter-satellite Interferometric Ranging

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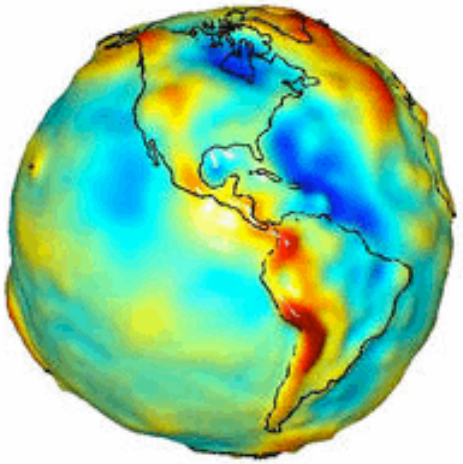
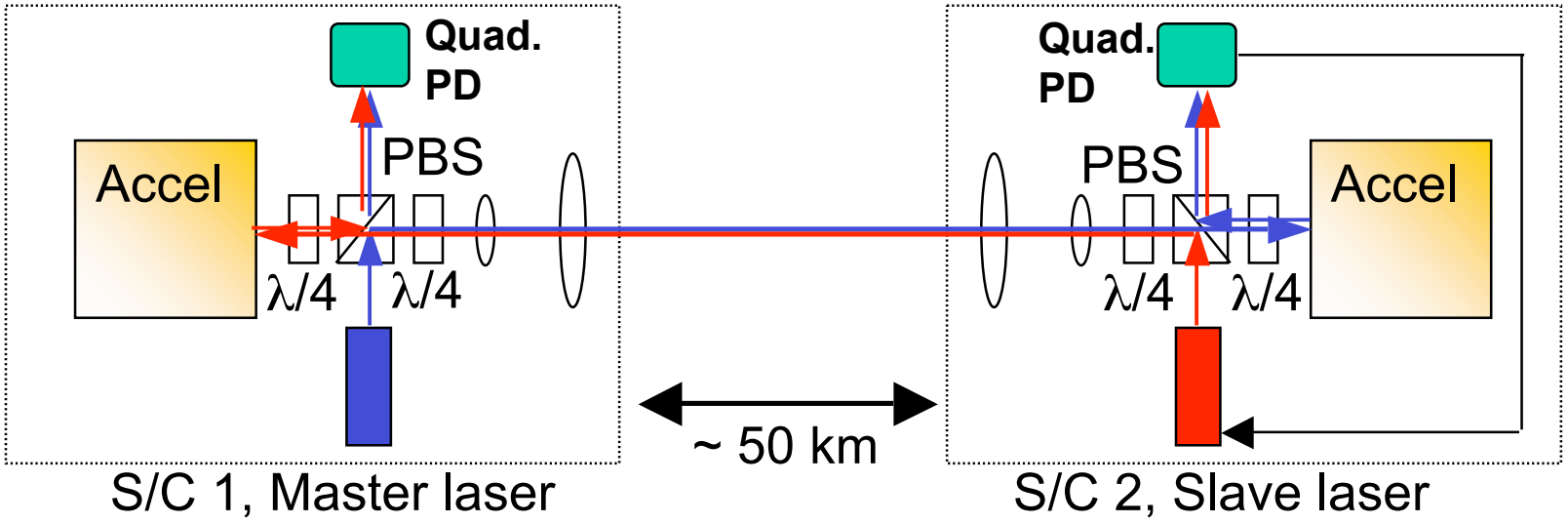
# Interferometric inter-satellite ranging for improved gravity spatial resolution

- Gravity Recovery and Climate Experiment (GR
  - Launched March 2002
  - Accelerometer at CG of sattelite
  - Microwave ranging between two satellites ~ 1 u
  - Applications to geodesy, hydrology, glaciology
  - www.csr.utexas.edu/grace/



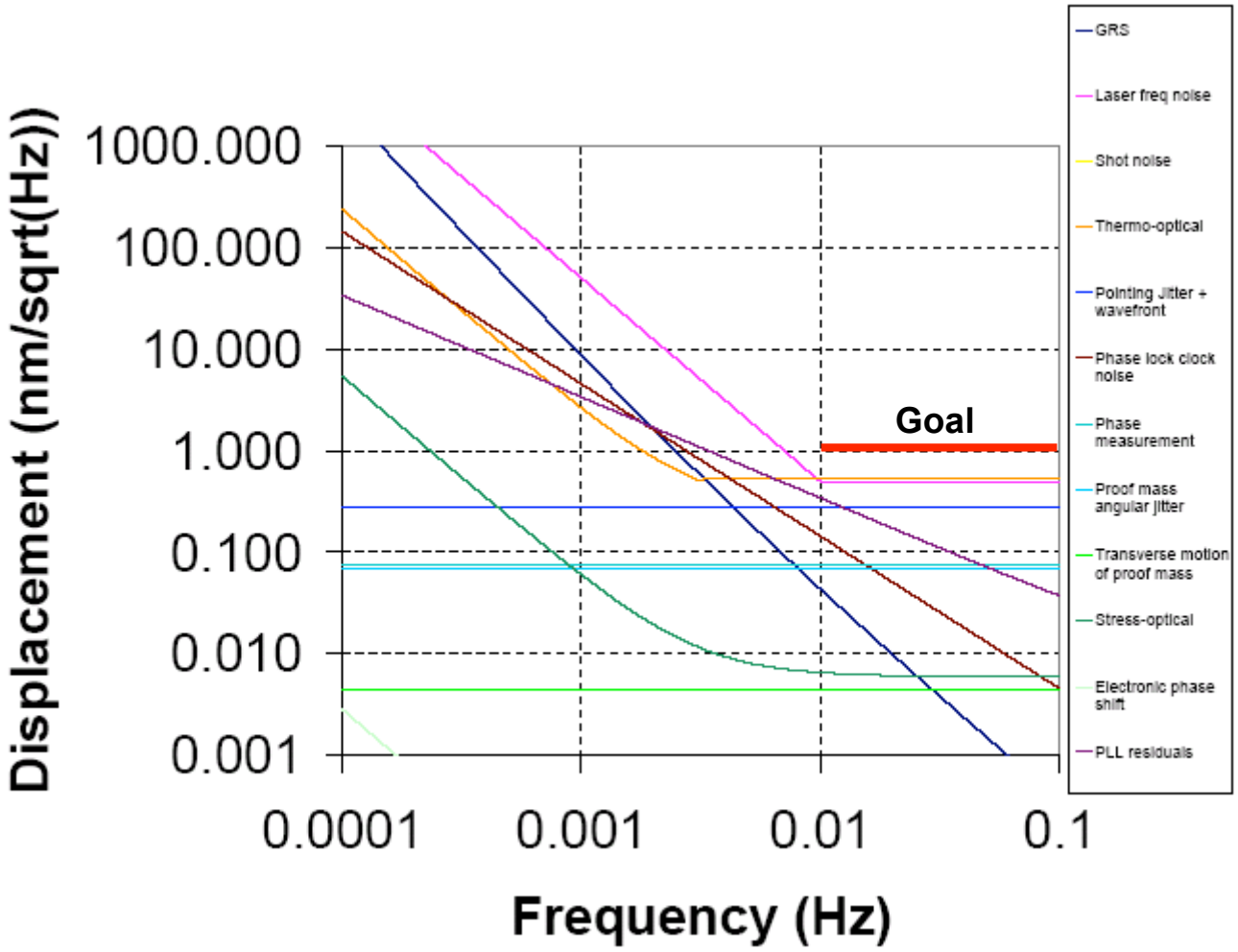
- GRACE measurements are limited at low frequencies by accelerometer errors and at high frequency by microwave phase noise
- To get improved spatial resolution
  - Improve accelerometer (ST7, LTP, LISA)
  - Decrease phase noise by moving to an optical interferometer

# Flight concept for an improved GRACE mission




- **Improved accelerometer with reflective proof mass at center of gravity of spacecraft (S/C)**
- **Drag-free operation of S/C**
  - **each S/C is controlled to follow proof mass with Micro-Newton Thrusters**
- **Frequency stabilized laser, 1.064 um**
- **Ranging from proof mass to proof mass with heterodyne interferometry to 1 nm/sqrt(Hz) level over frequencies of 10 to 100 mHz**

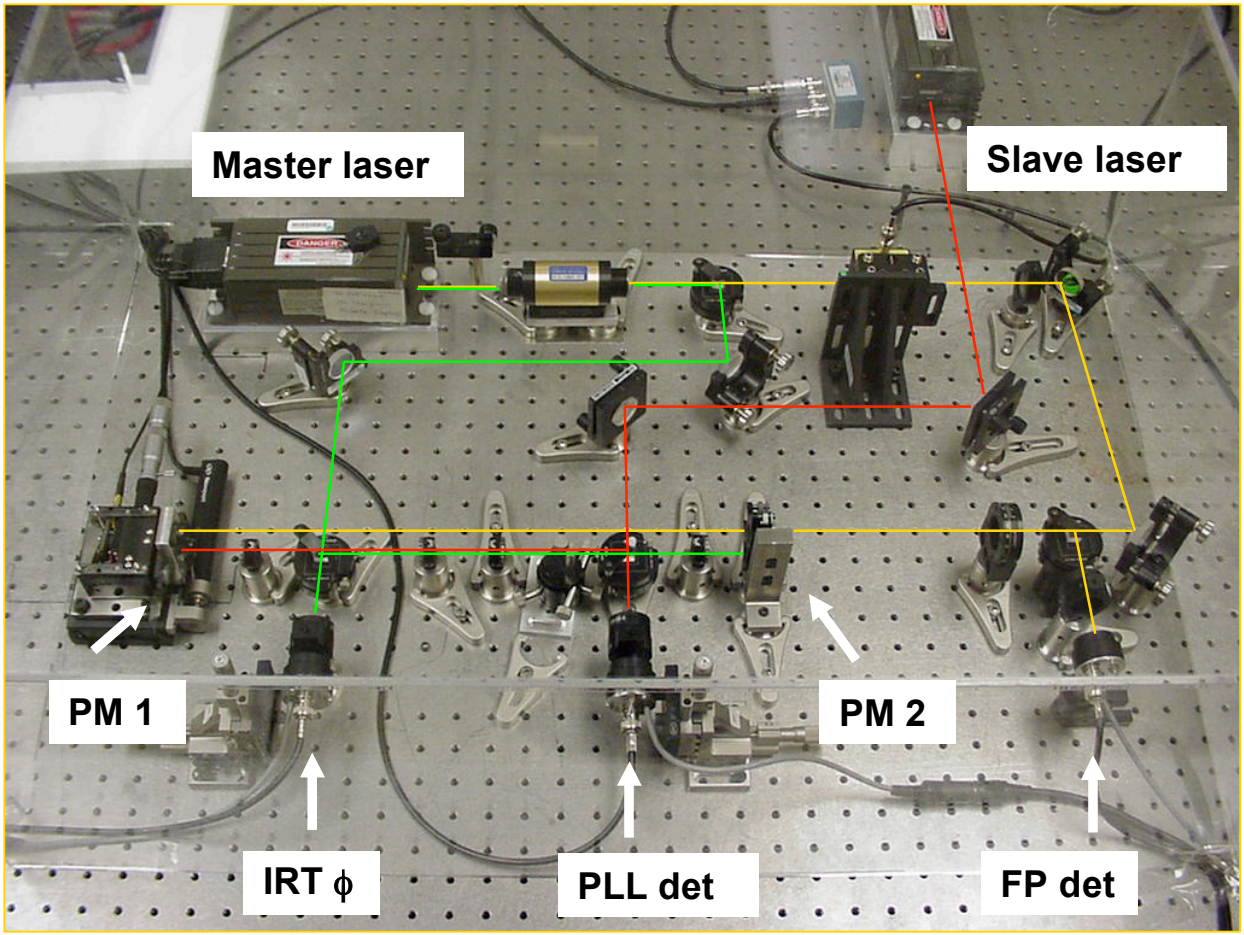
# Error budget based on flight concept guides laboratory demonstration




- Low Earth Orbit (LEO) thermal environment leads to dn/dT errors
- Wavefront distortion couples with pointing jitter
- Laser frequency noise looks like displacement noise.

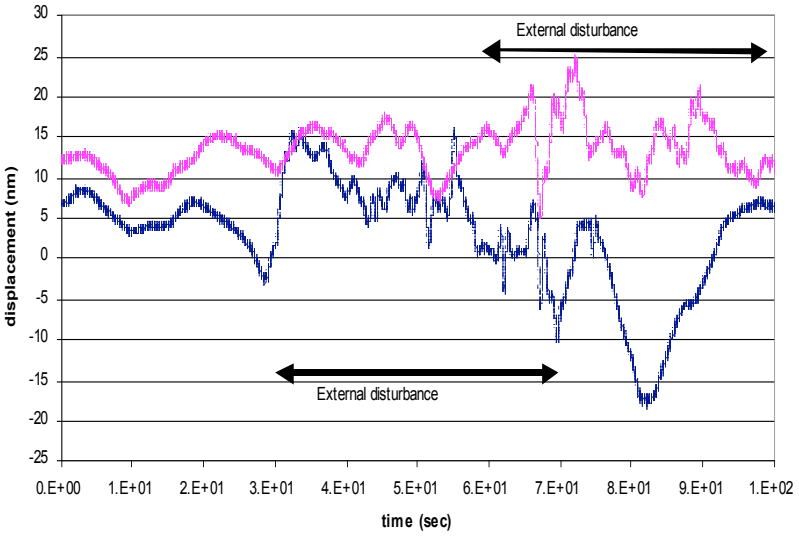
# Original breadboard designed and built to validate error budget in air

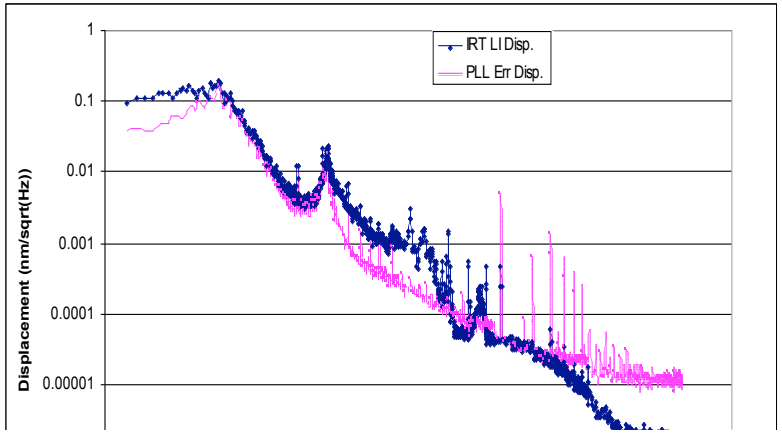
- No telescope
  - Wavefront distortion not measured
- Flat mirrors simulate proof masses
- Thermal environment uncontrolled
- Phase measured with JPL-provided Blackjack phasemeter



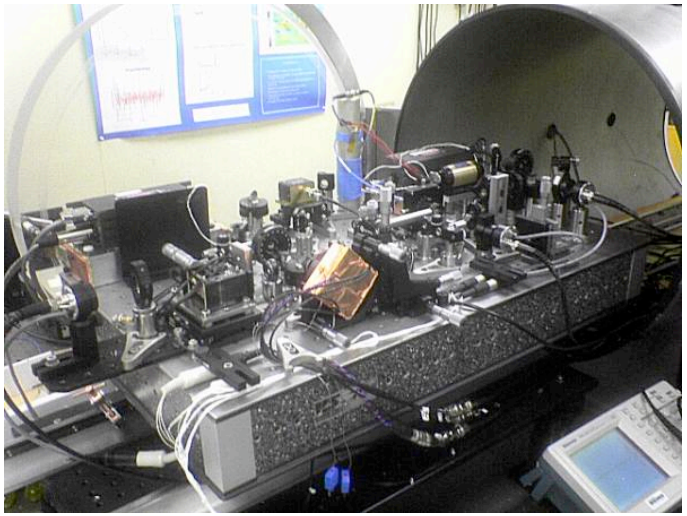
# Laboratory breadboard in air used to demonstrate initial performance

## Displacement noise in air; limited by air currents



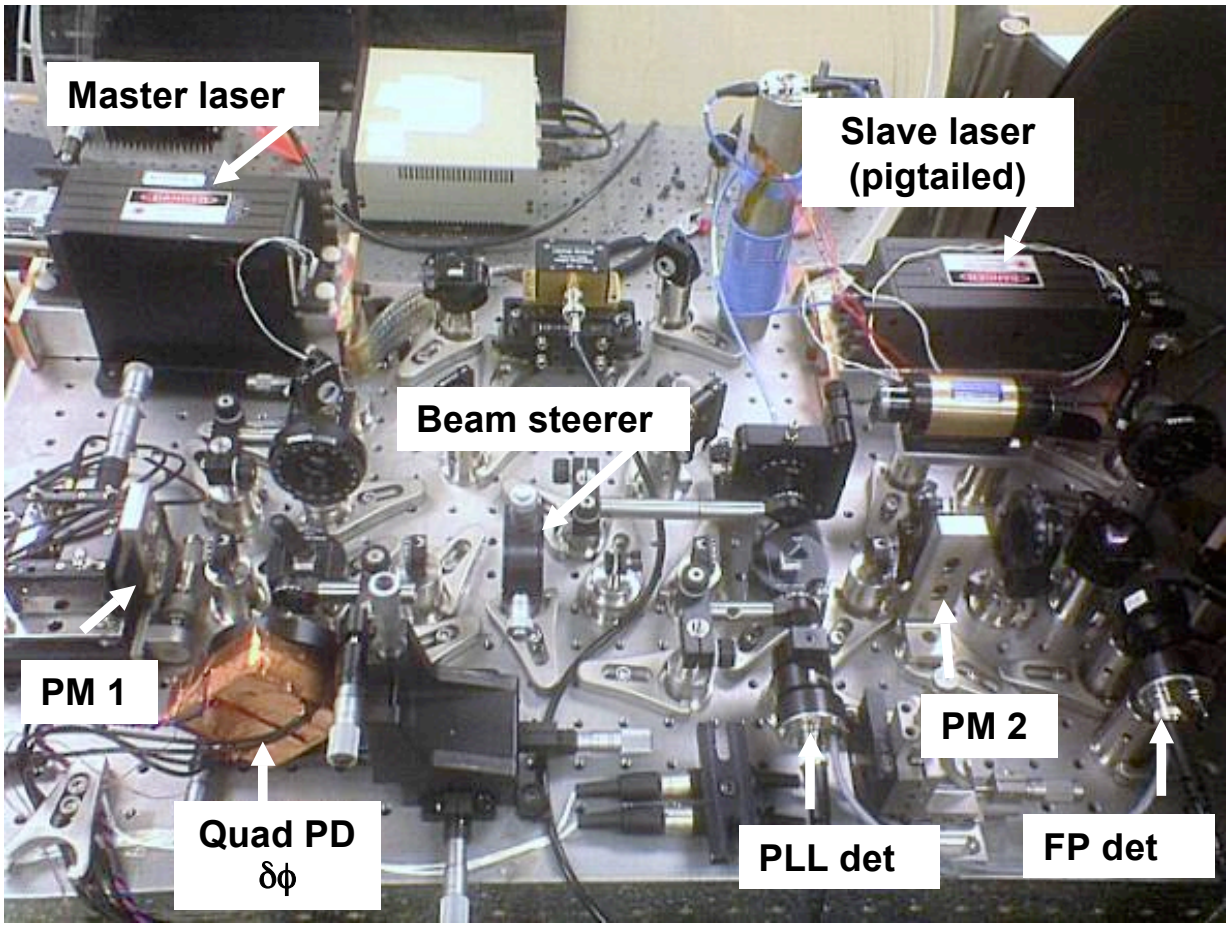




- **Displacement sensitivity limited by air**
  - **20 nm/sqrt(Hz) in an uncontrolled air path**
- **Characterized phase-locked loop (PLL)**
- **Validated pointing measurement capabilities**

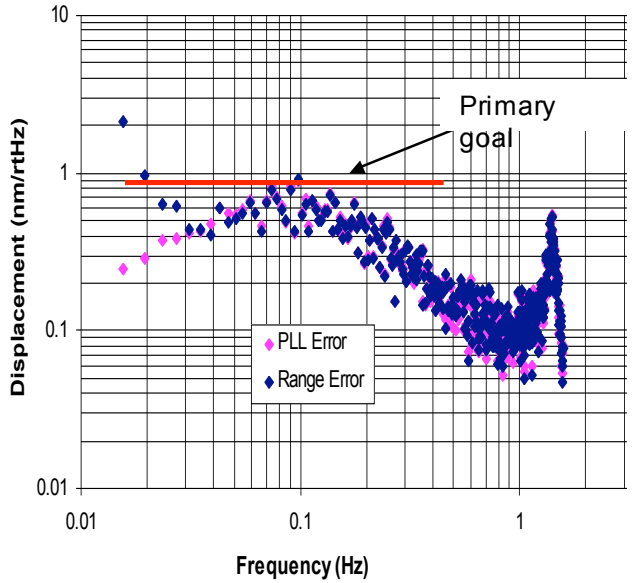


# Current Breadboard in Vacuum

- No telescope
  - Wavefront distortion not measured
- Flat mirrors simulate proof masses
- Thermal environment uncontrolled
- Beam steering and quadrant photodiode in place



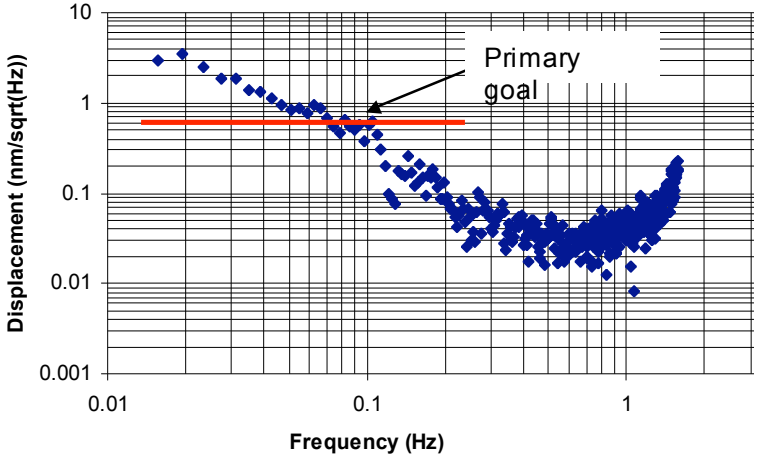
# Improved performance in vacuum has been validated with breadboard




Servo bump

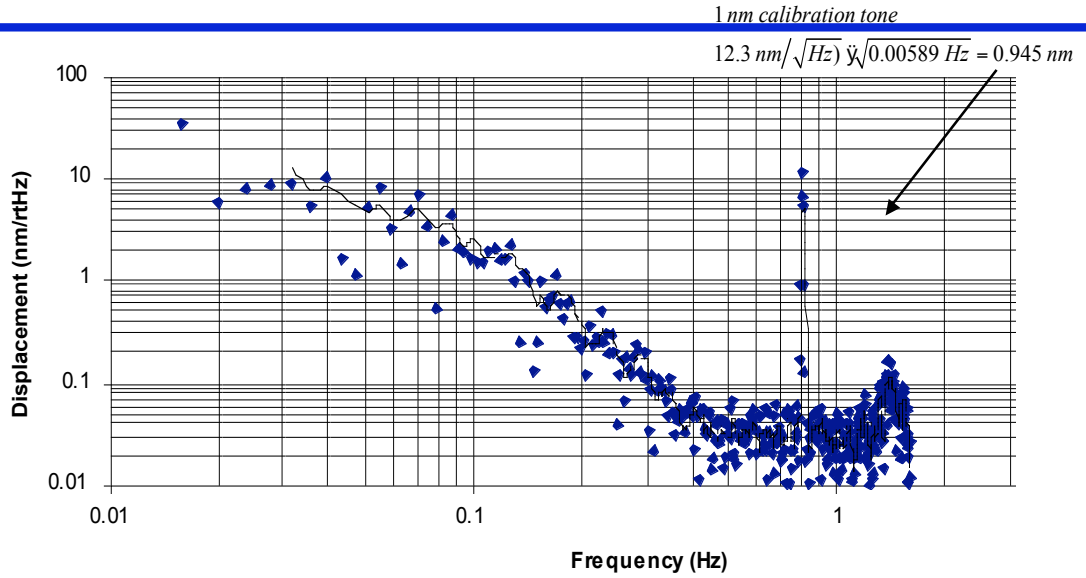
- Fabry-Perot control engaged
- Error component in range below 20 mHz (thermal drift?)

- Fabry-Perot control dis-engaged
- Error component in range below 40 mHz (drift?) expected to fade when lasers removed from breadboard.

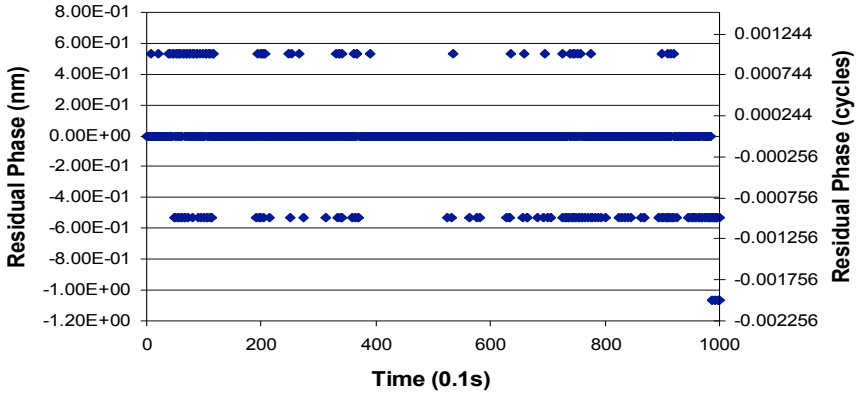


# Error terms have been validated by breadboard

- **Laser frequency noise**
  $\Delta\nu/\nu=\Delta L/L$ **to within 6%**
- **Clock noise**
  - **to digitization error**
- **PLL residuals**
  - **to digitization error**
- **Pointing noise**
  - **pointing model verified to within 5 %**
- **Blackjack well correlated to lock-in**

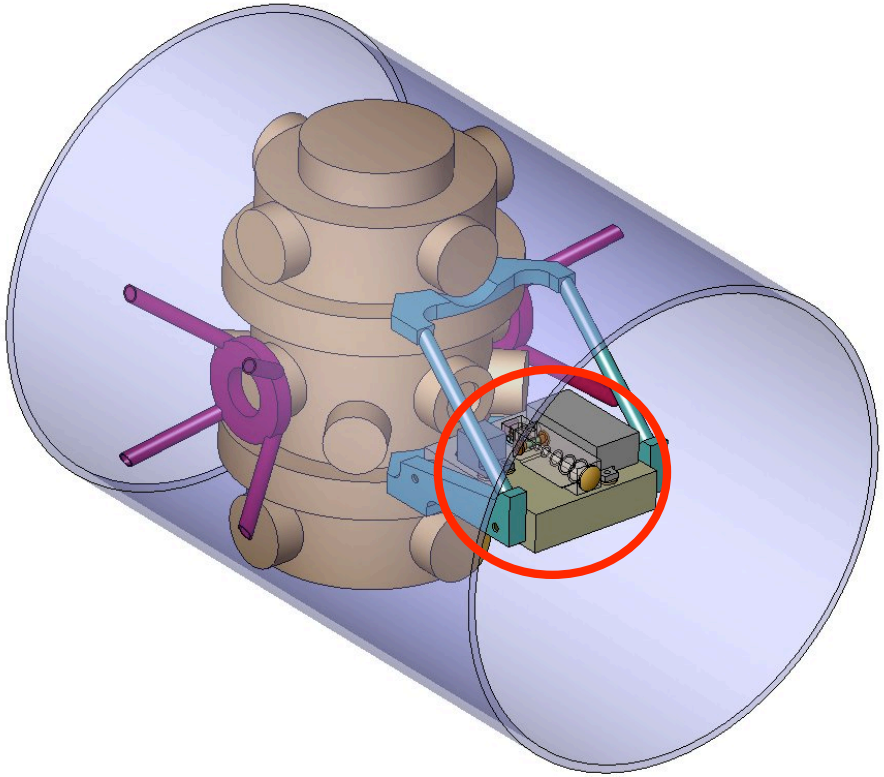



**PLL clock phase noise at output of interferometer with BJ**



# Goals for brassboard test

- **Demonstrate manufacturing capability for flight instrument**
  - **Survive launch vibrations**
  - **Survive non-operational temperatures**
  - **Excellent wavefront properties**
- **Demonstrate operational capabilities**
  - **Performance in presence of thermal fluctuations**
  - **Wavefront demonstration**
  - **Fundamental displacement sensitivity**
  - **Pointing measurement**
  - **Error budget validation**
- **Define interfaces**



Instrument concept

# Conclusions

- Interferometric inter-satellite ranging provides improved measurement of gravity variations
- An error budget for interferometric ranging in LEO has been developed
- Fundamental performance limits have been demonstrated in a laboratory environment
- Design underway to demonstrate performance of optical bench and ranging in relevant vibration and thermal environments